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Tall Fescue Response and Soil Properties Following Soil Amendment with Tannery Wastes

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16. ABSTRACT

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Tall Fescue Response and Soil Properties Following Soil Amendment with Tannery Wastes[1]

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ABSTRACT

Field plots were established in 1978 and 1979 on a Willamette sil (fine-silty, mixed, mesic pachic Ultic Argixeroll) in western Oregon to evalute the effects of chrome tannery wastes on tall fescue (*Festuca arundinacea* Schreb.) and soil properties. Three rates of waste material were applied each year; N, Ca, Mg, Cu, Cr, Mn, and Zn in soils and plants were analyzed to relate plant elemental concentrations and yield to elemental application and availability. Soil and fescue Cu, Zn, and Mg concentrations varied only slightly with waste application in either year. Soil total Cr levels increased as much as sevenfold with waste treatment; however, fescue Cr concentrations increased only slightly or not at all with waste application. The Mn concentration of tall fescue grown on waste-treated soils decreased compared to that of fescue grown on unamended soil in 1978 but increased with waste application in 1979, reflecting increased soil pH with waste application in 1978 but a decrease in 1979. Both fescue and soil Ca concentrations usually increased with waste application. Soil and fescue N concentrations and soil electroconductivity increased with waste application with the effect still observable 1 year after application. Fescue yields were greatest on soils treated with the highest rates of waste. Yields increased with waste treatment up to 3 years after application. With the exception of stand establishment problems, no detrimental effects of tannery waste on tall fescue were noted in 3 years of study.

Additional index words: Festuca arundinacea, Soil pH, Cr, Mn, Ca, Soil EC, N.

CHROME leather tanning processes are used extensively in the United States to stabilize hides for use in leather products. The industry produces over 150 000 Mg of waste each year (20). These wastes contain lime, hair, salts, and metals such as Cr, Cu, Mn, Zn, and Pb, as well as fats, oils, and dye residues.

Current tannery waste disposal practices include land filling and trenching, but since the wastes contain both lime and N, utilization in crop production could be an alternative method of disposal. Applications to agricultural land, however, may be limited by the presence of phytotoxic heavy metals in the waste. Metal concentrations in tannery wastes vary widely: 0.33 to 19 400 mg Cr kg^{-1}, 0.12 to 8400 mg Cu kg^{-1}, 0.75 to 240 mg Pb kg^{-1}, and 1.2 to 147 mg Zn kg^{-1} on a wet weight basis (20).

In a greenhouse experiment the Cr concentration of fescue (*Festuca arundinacea* Schreb.) grown on soils amended with 627 Mg ha^{-1} sewage sludge containing 0.7 mg Cr kg^{-1} was less than 0.2 mg kg^{-1} (19). Fescue grown on soils which received 43 mg Cr kg^{-1} in sewage sludge contained only 1.5 mg Cr kg^{-1}, indicating low availability to fescue (7).

In this study, the effect of Cr-containing tannery wastes on soil properties and fescue yield and the accumulation of N and metals in tall fescue was evaluated.

MATERIALS AND METHODS

'Fawn' tall fescue was planted on tannery waste-amended Willamette sil (fine-silty, mixed, mesic pachic Ultic Argixeroll) in field plots (2.3 × 4.6m) established at the North Willamette Exp. Stn., Aurora, Oreg., in June 1978 and 1979. Filter pressed blocks of combined beamhouse/tanyard waste from the Legallet Wool Co. (San Francisco, Calif.) were applied in 1978 but were no longer available in 1979. Separate beamhouse and lime-alum flocculated filter pressed tanyard wastes from the A. K. Salz Tannery (Santa Cruz, Calif.) were utilized in 1979. The beamhouse waste contained hair, lime, and chemicals used in the dehairing process; the tanyard waste contained dye residues, Cr, fat, oils, and small amounts of Cu, Mn, Pb, and Zn.

Tannery waste was applied in 1978 at rates designed to provide available N at approximately 180, 360, and 720 kg ha^{-1}, assuming that 18% of the total N was available the first season (Table 1). Ammonium nitrate (180 kg N ha^{-1}) with and without lime (22 Mg ha^{-1}) was broadcast on separate plots. Waste and lime were rototilled to 20 cm soil depth. The total NH_4NO_3 application was split into equal applications at seeding, 1 month after seeding, and following the first harvest. Four replications were arranged in randomized block design.

In 1979, beamhouse and tanyard wastes were applied to a second set of plots at a ratio to approximately duplicate the composition of the Legallet waste. Because only a limited amount of waste was shipped, the high application rate consisted solely of beamhouse waste and only three replications of each treatment were established. The total NH_4NO_3 application was split, with one-third applied at planting and the remainder after the first harvest. The NH_4NO_3 was reapplied in 1980.

Fescue was cut from the same 1.0 × 4.6 m strip in the center of each plot on 13 occasions from 1978 through 1981. Plant samples were dried and dry matter yields were calculated in 1978 and 1979. Only fresh yields were obtained in 1980 and 1981. Fescue established in 1978 was sampled twice in 1978 for elemental analysis. Fescue established in 1979 was sampled in September 1979 and again in April 1980.

Plant samples were dried at 70°C and ground in a Wiley mill to pass a 20 mesh screen. Total N was measured with a Technicon Auto Analyzer. Plant samples (1.0 g) were di-

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gested in HNO_3 (12.0 mL) and $HClO_4$ (6.0 mL), filtered, and diluted to 100 mL with distilled water for analysis of Ca, Mg, Cu, Cr, Mn, and Zn. In 1979, Cu was determined in plant samples (0.5 g) digested with HNO_3 and $HClO_4$ and heated to dryness. Ten milliliters of 1 *M* HCl were added, and the digests filtered 12 h later for analysis.

Soil samples (0 to 15 cm) collected in November 1979 and 1980 were air-dried and ground to pass a 2 mm sieve. Total Kjeldahl N (TKN) was determined following H_2SO_4 digestion and steam distillation (5). Nitrate- and NH_4-N were determined by steam distillation (6). Electroconductivity (EC) was determined in a saturated paste extract (4). Soil samples (0.5 g) for total Cr analysis and triplicate dried and ground waste samples (1.0 g) for total Cr, Cu, Mn, and Zn analysis were digested with HNO_3 (2.0 mL), HCl (3.5 mL), and HF (1.5 mL). The digests were shaken for 24 h at 50°C and diluted with 1.5% H_3BO_3 to a final volume of 50 or 100 mL.

Ten-gram soil samples were shaken for 2 h with 20 mL of diethylene-triaminepentacetic acid (DTPA) to extract Cu, Mn, and Zn (9). Separate soil samples were extracted with 1 *M* ammonium acetate and analyzed for Ca and Mg (14). Soil pH was determined in a soil water slurry (1:10) by glass electrode.

Plant and waste metal analysis was accomplished with an Applied Research Laboratory Inductively-coupled Plasma Spectrometer in 1978. Soil metal analysis in 1978 and all metal analyses in 1979 and 1980 were by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Tannery waste increased the pH of soils treated in 1978 when measured 17 months after application (Table 1). The pH of soils which received the largest amount of waste approximated that of lime-treated soils, about one unit higher than unlimed soils. In 1979, however, waste application decreased soil pH when measured either 5 or 17 months after application (Tables 1 and 2). The largest waste treatment in 1978 resulted in application of over 62 Mg ha^{-1} of $CaCO_3$ equivalent; the largest application in 1979 (beamhouse material only) contained only 4.5 Mg ha^{-1} $CaCO_3$ equivalent. Apparently, the lime content of the 1979 waste was not sufficient to overcome the acidifying effect of waste mineralization. Similarly, the pH of soil beneath a tannery waste disposal site decreased 0.7 units, probably caused by CO_2 production or nitrification in the waste (16).

Diethylene-triaminepentacetic acid-extractable soil Mn levels increased with waste application in 1979 but not in 1978 (Table 1), although approximately nine times more Mn was applied at maximum rates of waste application in 1978 (Table 3). Lower Mn levels in 1978 probably resulted from reversion to less soluble forms with increasing soil pH. Since different waste sources were used for the 2 years, the forms of Mn added may also have differed.

In agreement with the soil analysis results, the Mn concentration of fescue grown on tannery waste treated soils increased relative to plants grown on untreated soils in 1979 but not in 1978 (Table 4). All fescue Mn concentrations were less than the 500 mg kg^{-1} level considered toxic (8, 11, 12).

Waste application slightly increased the Cu concen-

Table 1. Analysis of Willamette sil treated with NH_4NO_3 or tannery wastes.†

Treatments, 1978								Total	Extractable				
Waste	Lime	NH_4NO_3-N	pH	EC	TKN	NH_4-N	NO_3-N	Cr	Cu	Mn	Zn	Ca	Mg
Mg ha^{-1}		kg ha^{-1}		dS m^{-1}	g kg^{-1}	mg kg^{-1}						g kg^{-1}	
0	0	0	6.4	0.2	1.2	1.2	1.1	52	0.37	52	0.6	1.6	0.12
0	0	180	6.4	0.2	NA‡	NA	NA	51	0.38	45	0.6	1.2	0.12
0	22	180	7.2	0.3	1.3	2.6	1.5	56	0.32	28	0.4	3.6	0.11
43	0	0	6.6	0.2	1.3	2.5	1.7	54	0.37	36	0.7	1.9	0.11
86	0	0	6.8	0.3	1.3	2.3	1.5	60	0.38	44	0.8	2.4	0.11
171	0	0	7.3	0.5	1.8	3.5	1.5	160	0.39	54	1.0	4.4	0.10
		LSD ($P \leq 0.05$)	0.2	0.1	NS§	1.0	NS	28	NS	16	0.3	0.8	0.01
Treatments, 1979													
0	0	0	5.9	0.2	1.2	2.1	1.2	39	0.43	48	0.6	1.2	0.12
0	0	180	5.9	0.3	1.2	2.6	1.6	33	0.33	40	0.6	1.2	0.12
23	0	0	5.7	0.9	1.3	2.5	2.1	132	0.41	56	0.8	1.5	0.10
46	0	0	5.8	1.9	1.4	5.6	3.6	264	0.41	64	0.8	1.9	0.10
57	0	0	5.3	2.5	1.8	6.6	16.4	37	0.31	143	1.2	3.6	0.08
		LSD ($P \leq 0.05$)	0.2	0.5	0.5	1.6	5.	166	NS	13	NS	0.3	0.01

† Collected in November 1979.
‡ NA = Not analyzed.
§ NS = Not significant.

Table 2. Analysis of Willamette sil treated with NH_4NO_3 or tannery wastes.†

Treatments						Extractable				
Waste	NH_4NO_3-N	pH	EC	N	Total Cr	Cu	Mn	Zn	Ca	Mg
Mg ha^{-1}	kg ha^{-1} $year^{-1}$		dS m^{-1}	g kg^{-1}	mg kg^{-1}				g kg^{-1}	
0	0	5.8	0.3	0.9	47	0.45	12	0.5	1.7	0.16
0	180	5.7	0.3	1.1	44	0.44	14	0.6	1.7	0.16
23	0	5.7	0.3	1.1	139	0.52	14	0.7	2.2	0.12
46	0	5.6	0.9	1.3	195	0.50	12	0.9	2.3	0.10
57	0	5.2	2.5	1.8	42	0.38	17	1.3	3.8	0.06
	LSD ($P \leq 0.05$)	0.2	0 5	0.2	87	0.07	5	NS‡	0.4	0.02

† Collected in November 1980 from plots established in 1979.
‡ NS = Not significant.

tration of fescue harvested in August 1978, compared to the concentration in plants grown on untreated soils (Table 4); however, DTPA-extractable soil Cu concentration did not increase with waste application in 1978 (Table 1). Neither plant nor soil Cu content increased with waste application in 1979 (Tables 1 and 4). Soil Cu levels were greater than the 0.2 mg kg^{-1} level needed for good plant growth (9). Applications of from 1 to 10 kg Cu ha^{-1} to mineral soils is considered adequate to correct Cu deficiency in many crops (13). Amounts of Cu applied with tannery waste (Table 3) could, with repeated applications to soil, result in toxic levels; however, all plant samples collected had Cu contents less than 20 mg kg^{-1}, a level considered toxic to many plants (1).

In 1978, the largest waste treatment resulted in application of 787 kg Cr ha^{-1} and significantly increased the total Cr concentration of the treated soils (Table 1). Fescue Cr concentration increased slightly with waste application compared to untreated soils, but was not significantly higher than in fescue grown on soils amended with NH_4NO_3 (Table 4).

Waste application did not significantly affect the Cr content of fescue established in 1979 (Table 4), although application of mixed tannery wastes (low and intermediate rates) increased total soil Cr levels three- to sevenfold. The beamhouse waste (high rate) did not affect soil Cr content (Table 1), in agreement with the much lower amount of Cr applied (Table 3). In general, fescue Cr concentrations did not correlate strongly with soil Cr content.

Trivalent Cr, the form present in tannery waste, is less readily transported to aerial portions of plants than is the more toxic and mobile Cr VI (15, 17). Since oxidation of Cr III to Cr VI can occur in moist soil (2) and is known to increase with increasing soil pH (17), plant uptake or leaching of Cr VI may have occurred on the plots established in 1978. Chromium VI was not specifically analyzed in this study.

Fescue Zn concentration increased with waste application in 1979 but not in 1978 (Table 4), even though Zn applications were much higher in 1978 (Table 3). In 1979, the greatest Zn concentration occurred in fescue grown on the soils which received only beamhouse waste (Table 4). Soil extractable Zn levels also tended to be highest with this treatment (Tables 1 and 2), but the increase was not statistically significant. The decrease in soil pH with the beamhouse waste treatment (Table 1) may have caused the increased fescue Zn concentration in 1979. The increase in soil pH with waste application in 1978 appeared to offset any effect of Zn applied with the waste.

Tannery waste generally increased the TKN, NH_4-N, and NO_3-N content of surface soils collected in November, 1979 from plots established in 1978 or 1979 (Table 1). When measured in November 1980, the TKN of waste-treated soils still exceeded that of untreated soils, more than 17 months after application (Table 2).

Nitrogen concentration of all fescue samples collected at first harvest in 1978 were within or above the critical range of 28 to 34 g kg^{-1} (10) and increased with waste application, but were highest in plants fertilized with NH_4NO_3 (Table 4). At the second harvest, fescue N levels declined, but still increased with waste application. For fescue established in 1979, the highest N concentrations occurred in plants grown on soils amended with the higher rates of waste (Table 4). In April 1980 (Table 4), the highest N concentrations also occurred in plants grown on waste-amended soils. Apparently, mineralization of waste organic N supplied significant amounts of available N 10 months following waste application. The total N application was highest with 57 Mg ha^{-1} of beamhouse waste (Table 3), and was reflected in tissue and soil N levels (Tables 1, 2, and 4).

The highest yields for the first two cuttings of fescue established in 1978 occurred on soils fertilized with

Table 3. Amounts of elements applied to soil with the largest waste treatments.

Element	1978†	1979	
		Mixed‡	Beamhouse§
	kg ha^{-1}		
TKN	4 275	2 570	4 390
NH_4-N	229	51	34
NO_3-N	10	6	7
Cr	787	1 125	0.1
Cu	4.1	1.7	0.2
Mn	582	25	61
Zn	23.9	2.4	1.8
Cd	0.007	0.002	0.0005
Ca	24 790	1 300	1 770
Mg	410	75.5	28.5
Na	273	227	228

† 171 Mg ha^{-1} of a combined beamhouse-tanyard waste.
‡ 21 Mg ha^{-1} beamhouse waste plus 25 Mg ha^{-1} tanyard waste.
§ 57 Mg ha^{-1} beamhouse waste.

Table 4. Elemental composition of tall fescue grown on tannery waste-amended Willamette sil.

Sampling date	Treatments, 1978			N	Cr	Cu	Mn	Zn	Ca	Mg
	Waste	Lime	NH_4NO_3-N							
	Mg ha^{-1}		kg ha^{-1}	g kg^{-1}	mg kg^{-1}				g kg^{-1}	
9-1-78	0	0	0	32	7.5	4.4	151	22	2.2	2.4
	0	0	180	46	12.1	NA†	122	25	2.7	2.9
	0	22	180	48	10.9	4.2	81	22	3.0	2.9
	43	0	0	34	8.8	5.4	106	22	2.2	2.4
	86	0	0	40	12.4	5.0	114	23	2.9	2.8
	171	0	0	42	10.4	5.7	131	24	4.5	2.8
		LSD ($P \leq 0.05$)		5	2.5	0.8	27	NS‡	1.0	NS
10-19-78	0	0	0	19	10.8	4.6	196	18	4.7	2.6
	0	0	180	NA	12 7	NA	152	19	3.4	2.7
	0	22	180	NA	15.4	4.6	94	16	4.8	2.7
	43	0	0	23	9.1	4.7	152	18	4.9	2.6
	86	0	0	26	10.8	4.9	157	19	4.7	2.6
	171	0	0	29	14.8	5.1	175	20	5.0	2.8
		LSD ($P \leq 0.05$)		4	3.4	NS	25	2	NS	NS
	Treatments, 1979									
9-21-79	0	0	0	22	3.9	5.4	179	7	4.2	1.7
	0	0	180	26	NA	NA	191	12	4.8	2.0
	23	0	0	24	4.7	5.3	205	11	4.8	1.7
	46	9	0	29	7.4	5.8	248	18	6.3	2.0
	57	0	0	31	4.3	6.3	440	24	7.6	2.1
		LSD ($P \leq 0.05$)		3	NS	NS	41	7	0.4	0.3
4-02-80	0	0	0	11	3.8	3.5	301	15	9.8	1.8
	0	0	180	16	2.7	4.1	292	23	9.1	1.9
	23	0	0	14	3.7	4.0	324	17	12.2	2.0
	46	0	0	18	4.1	4.5	337	16	12.6	2.2
	57	0	0	24	5.4	5.3	300	21	8.5	2.2
		LSD ($P \leq 0.05$)		4	1.9	NS	NS	4	2.6	NS

† NA = Not analyzed.
‡ NS = Not significant.

Table 5. Dry matter yield of tall fescue grown on tannery waste-amended Willamette sil.

Treatments, 1978			Harvest date					
Waste	Lime	NH_4NO_3-N	9-1-78	10-19-78	4-25-79	6-22-79	8-22-79	Total
Mg ha^{-1}		kg ha^{-1}	Mg ha^{-1}					
0	0	0	3.7	0.7	0.3	0.7	0.2	5.6
0	0	180	4.9	2.3	1.2	1.0	0.2	9.6
0	22	180	4.9	2.1	1.4	1.0	0.3	9.7
43	0	0	4.3	1.0	0.8	1.0	0.2	7.3
86	0	0	5.0	1.6	1.4	1.4	0.3	9.7
171	0	0	4.9	2.0	2.3	1.8	1.1	12.1
		LSD ($P \leq 0.05$)	0.6	0.5	0.5	1.0	0.3	1.1

Treatments, 1979			Harvest date			
Waste	Lime	NH_4NO_3-N	8-22-79	9-21-79	11-9-79	Total
0	0	0	1.5	1.9	1.0	4.4
0	0	180	2.2	3.5	1.3	7.0
23	0	0	2.3	2.5	1.2	6.0
46	0	0	2.4	3.2	1.3	6.9
57	0	0	2.0	3.3	3.0	8.3
		LSD ($P \leq 0.05$)	NS†	NS†	0.6	1.0	1.1

† NS = Not significant.

Table 6. Fresh weight yield in 1980 and 1981 of tall fescue grown on tannery waste-amended Willamette sil.

Treatments applied in						Harvest date						
1978			1979		1980	1980				1981		
Waste	Lime	NH_4NO_3-N	Waste	NH_4NO_3-N	NH_4NO_3-N	4-20	5-23	7-15	11-28	4-17	7-13	Total
Mg ha^{-1}		kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	Mg ha^{-1}						
1978 plots												
0	0	0	0	0	0	–	5.4	3.3	0.1	1.1	2.1	15.0
0	0	180	0	0	0	–	9.4	3.9	0.1	1.1	1.9	16.4
0	22	180	0	0	0	–	9.4	3.9	0.1	1.2	2.0	16.6
43	0	0	0	0	0	–	9.1	4.3	0.1	1.7	1.9	17.1
86	0	0	0	0	0	–	12.5	5.7	0.3	2.2	2.9	23.6
171	0	0	0	0	0	–	25.4	7.9	1.8	3.7	4.9	43.7
					LSD ($P \leq 0.05$)	–	4.8	1.6	0.4	0.3	1.1	6.4
1979 plots												
			0	0	0	1.3	5.8	1.5	0.1	0.6	1.5	10.8
			0	180	180†	3.8	21.1	9.5	0.5	1.7	2.6	39.2
			23	0	0	3.7	9.9	3.2	0.1	1.5	2.8	21.2
			46	0	0	5.7	12.2	3.4	0.4	2.7	3.6	28.0
			57	0	0	8.1	18.0	6.2	3.6	8.9	5.8	50.6
					LSD ($P \leq 0.05$)	2.6	7.7	2.2	2.3	2.3	0.7	8.4

† NH_4NO_3 applied (60 kg N/ha) on 4/2/80, 4/20/80, and 5/23/80.

NH_4NO_3 or the intermediate or high rate of waste (Table 5). Since the NH_4NO_3 was not reapplied, fescue yields rapidly declined to equal yields from untreated soils. Fescue yields on soils treated with intermediate or high rates of waste remained significantly higher than yields on untreated soils throughout the four growing seasons (Tables 5 and 6).

Fescue stand establishment on soils amended with the high rate of waste in 1979 was initially poor. In a similar study with sweet corn (*Zea mays* L.), seedlings were initially slightly stunted at high rates of waste application (18). In both these instances, the high EC of waste-amended soil probably contributed to poor early plant growth (3).

For fescue established in 1979, yield responses to NH_4NO_3 and the higher rates of tannery waste were approximately equal for the first two harvests. The total yield for the growing season, however, was greatest on soils amended with the high rate of waste (Table 5). Since NH_4NO_3 was reapplied in 1980, total yields in 1980 were approximately equal for fescue grown on NH_4NO_3-treated soils and those previously treated with the high rate of tannery waste (Table 6). In 1981, NH_4NO_3 was not reapplied; greatest yields occurred on soils treated with the high rate of waste.

If one assumes that the primary cause of fescue yield increases on waste-amended soils is increased N availability, and assuming linear yield response to available N, the amount of N utilized by the fescue can be estimated as follows:

$$\text{N utilized (kg ha}^{-1}) = \frac{180 \text{ kg N ha}^{-1} (a-b)}{(c-b)},$$

where a = yield from waste amended soil; b = yield from unfertilized soil; c = yield from soil treated with 180 kg N ha^{-1} as NH_4NO_3.

For fescue established in 1979, this formula provides an estimate of 270 kg ha^{-1} of waste N utilized by the fescue in 1979 on soils amended with the high rate of waste. Similarly, in 1980, the residue from the high rate of waste provided approximately 186 kg N ha^{-1} to the fescue crop. A similar estimate is not possible for 1981, but the yield response to residual waste in 1981 indicates that considerable waste N was still

becoming plant available. Thus, the benefits of waste utilization may be realized for at least 3 years following application.

The high $CaCO_3$ equivalence of some tannery wastes could be advantageous on acidic soils and should reduce uptake of waste-borne toxic metals. In this study the soil pH was sufficiently high (pH 6.4 in 1978) that fescue yields did not increase from addition of lime with the NH_4NO_3 fertilizer (Table 5). Likewise, the lime content of the 1978 waste probably contributed little to its value as a fertilizer on Willamette sil; thus, the tannery waste would be valuable primarily as an N source. Salt content, as well as Cr concentration, may limit rates of tannery waste application to cropland.

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